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STATCOM Model for Integration of Wind Turbine to Grid

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Abstract

The system stability is greatly hampered when green electricity is feed into the conventional electricity network due to intermittent nature of renewable sources. The electricity generation from wind so far predominates than that of other renewable sources. In order to maintain system stability of the electricity network, IEC-61400 (International Electro-technical Commission) standard has defined for performance and power quality of wind turbine. The power quality issues like frequency, voltge sag and swell, active and reactive power, flicker and harmonics are needed to be considered in case of integration of green electricity to grid. Various FACTS (Flexible AC transmission system) devices are used for system restoration. In this paper, a STATCOM (static compensator) model is proposed for improving the power quality in case of feeding generated electricity from the wind turbine into the grid. The STATCOM is connected at a point in between doubly fed induction generator based wind turbine and grid with a storage option.The STATCOM model is designed and simulated by MATLAB Simulink. The simulation results indicate that the bus voltage intially starts to decrease from the rated value of 1 pu and later it stabilizes to 1 pu due to addition of STACOM in the designed system.

***Keywords**: power quality, reactive power, FACTS, STATCOM*

1. Introduction

The electricity generation greatly depends on the conventional energy sources which becomes the major emitter of green house gases in the environment [1]. In order to reduce the green house gas emission and dependency on conventional energy sources, the utilization of renewable energy sources for electricity generation is increasing day by day. Due to the intermittent nature of electricity generation from renewable sources, the integration of green electricity to the grid causes instability in overall power system [2]. Among different renewable technologies, the wind technology is considered to be the proven technology for large scale electricity generation. The American Wind Energy Association (AWEA) led the effort in the United States for adoption of the grid code for the interconnection of the wind plants to the utility system [2, 3]. The United State wind energy industry took a stand in developing its own grid code for contributing to a stable grid operation [3]. The performance and power quality of wind turbine is determined by IEC-61400-21 (International Electro-technical Commission) standard which clearly emphasizes on system stability in case of feeding electricity to the grid [4]. When wind power is fed into the grid, various unbalances like voltage sag, voltage swell, flicker and harmonics cause variation of system voltage, frequency, real and reactive power [3, 4].

The compensation of reactive power for system stability is the major concern for complex power system network [4]. Generally series and shunt compensation is used for reactive power compensation. In recent years, the STATCOM is used for improving power system stability and performance [6]. The application of VSCs (voltage source converters) in the transmission system became the subject of considerable research effort in the late 1980s and through the 1990s [6]. The VSC based FACTS devices include STATCOM, SSSC (series static synchronous compensator), UPFC (unified power flow controller), and IPFC (interline power flow controller) [4, 6]. In the past ten years, pilot installations of STATCOM, UPFC, and IPFC have been built and commissioned. However, the considerable price of all VSC based FACTS device is main impediment to their widespread use [6, 8]. The STATCOM has much better

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transient response and performance in case of transient disturbances as compared to that of static var compensator [6, 7].

2. Wind Turbine and Electricity Generation

Wind turbine generators may be categorized into two major types (i) constant speed units, and (ii) variable speed units [2]. Constant speed wind turbine generators which are singly fed essentially run at a relatively fixed mechanical speed [1]. These units are most typically induction machines i.e. high efficiency induction motors running at super synchronous speed [2]. The major advantages of the variable speed designs are that they have a higher efficiency and better power quality. In addition, variable speed units which are doubly-fed induction machines can generate and absorb reactive power and thus regulate their apparent power factor [2, 3]. In contrast, the standard induction generator designs consume reactive power and thus typically employ shunt compensation both at the location of the wind turbine and possibly at the substation connecting the wind farm to the system [3, 4].

The most common type of variable-speed wind generation is the use of doubly-fed induction generators (DFIG) which is shown in the Figure 1. This design employs a series voltage-source converter to feed the wound rotor of the machine [2]. By operating the rotor circuit at a variable frequency it is possible to control the mechanical speed of the machine [1]. In this design the net output power of the machine is a combination of the power coming out of the machine's stator and that from the rotor and through the converter into the system [2].

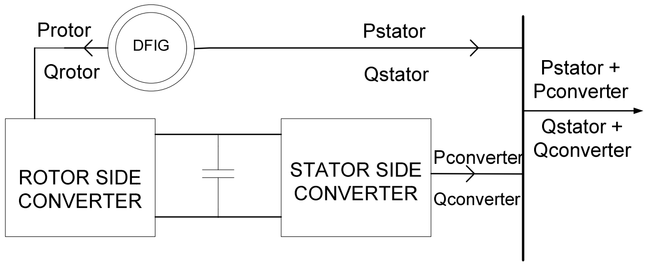

Figure 1. Block Diagram of Doubly Fed Induction Generator

The electricity generation is more stable by using DFIG generator than that of conventional synchronous generator [3]. The electricity generation by conventional synchronous generator (SG) and DFIG are shown in Figure 2 and 3 respectively. It can be observed from the figures that the generated voltage is more stable with DFIG than that of SG.

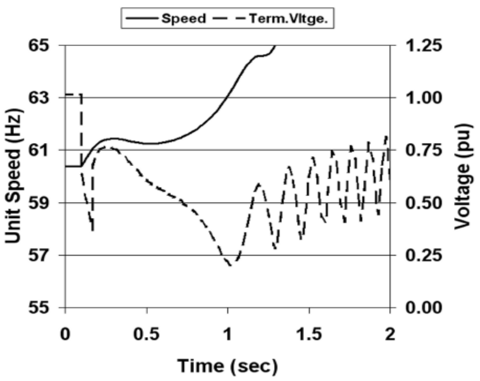

Figure 2. Electricity Generation by SG

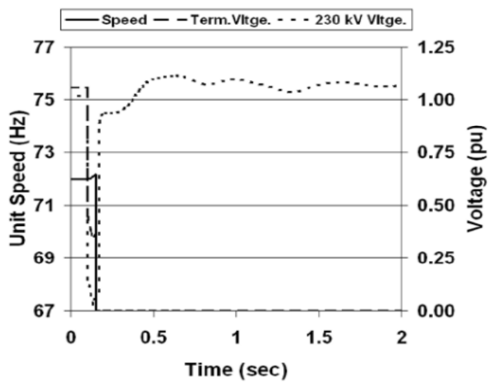

Figure 3. Electricity Generation by DFIG

3. Problems in Integrating Wind Turbine to Grid

The voltage dips is one of the most common consequence which may cause due to integration of green electricity as well as variation of system load [5]. Many electrical machines can easily ride through short term voltage dips (which can be a single or three phase dip, single phase being the most common) [9]. The voltage dip causes widespread failure of equipments with shortened lifetime. Moreover the long term voltage dips may trip or shutdown generators in power station [5, 6]. According to the National Electric Machines Association (NEMA) MG1-1993 standard the voltage imbalance for induction machines should be kept less than 1% in USA [4]. However due to voltage variation in the electrical network may cause 3% unbalance in induction machines [4, 6]. Harmonics in the power system arise due to the presence of non-linear loads which can produce significant 3rd, 5th, 7th, and 11th harmonics [8, 11]. The deleterious effects of harmonics on the power system are system capacitors draw excessive currents that can lead to damage, system resonance may occur which can result in over voltage and frequency, excessive losses occur in transformers, commutation failure of SCR based converters and low system power factor [5, 8]. The variation of system load also causes changes in system voltage, frequency and power factor from the rated values at the consumer end [10]. The poor power factor means very poor utilization of the power network infrastructure [5]. However by using suitable FACTS devices for reactive power compensation can control the variation of system voltage within the permissible limit [3]. This also eliminates the effect of harmonics due to rapid switching of connected load and generators [3, 4].

A STATCOM is a shunt device which is used to compensate the reactive power in power system and thereby stabilizes the system voltage [6]. The STATCOM generally uses a voltage source converter (VSC) interfaced in shunt to a transmission line [7]. In most cases the DC voltage support for the VSC is provided by the DC capacitor of relatively small energy storage capability [8]. In steady state operation, the active power exchanged with the line is maintained to zero which is shown in the Figure 4.

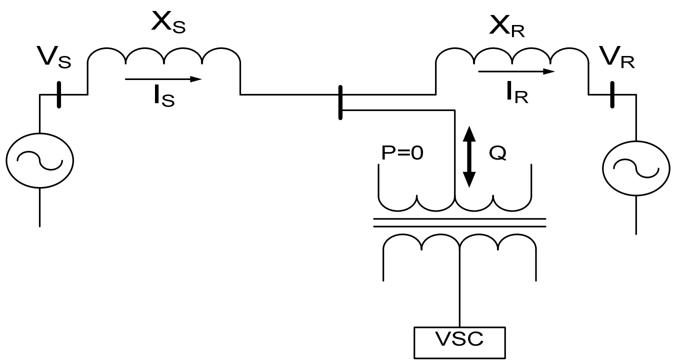

Figure 4. Basic Block Diagram of STATCOM

The STATCOM is in contradiction to the more traditional SVC (Static VAR Compensator), not depending on the applied voltage for injecting or absorbing the demanded reactive power. This ability makes the STATCOM advantageous for regulation of the system voltage at the point of common coupling (PCC) [6, 7]. There are two types of STATCOM, the current-source converter based (CSC) and the voltage source converter (VSC) or voltage source inverter (VSI) based [10]. The VSC-based STATCOM compromises a PWM (Pulse Width Modulation) controlled IGBT (Insulated Gate Bipolar Transistor) based inverter with a DC bus capacitor [6]. In contradiction to the traditional reactive compensators, such as condenser banks, where the capacitor size is directly related to the compensating capability, the DC capacitors of the STATCOM are of no direct connection to the reactive power supply whose purpose is to maintain a steady DC bus voltage [7, 9].The STATCOM has much better transient performance as compared to the traditional reactive power compensator and is far superior in terms of cost, weight and size [5]. STATCOMs do not have the harmonic problems like SVC and offer very fast response to transient disturbances on network [6, 11]. A commonly used model of

DFIG with STATCOM which is used for wind turbine for feeding electricity into the grid is shown in the figure 5.The stator of the wound rotor induction machine is connected to the low voltage side whereas the rotor is fed via the back-to-back IGBT voltage source inverters with a common DC bus [3, 6]. The network side inverter controls the power flow between the DC bus and the AC side and allows the system to be operated in sub-synchronous and super-synchronous speed [5, 6]. The proper rotor excitation is provided by the machine side inverter.

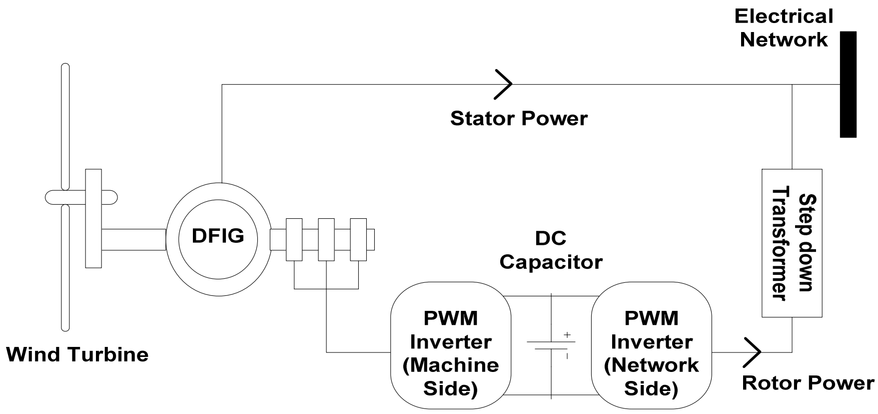

Figure 5. Model of DFIG Wind Turbine

4. Simulated Model of DFIG with STATCOM

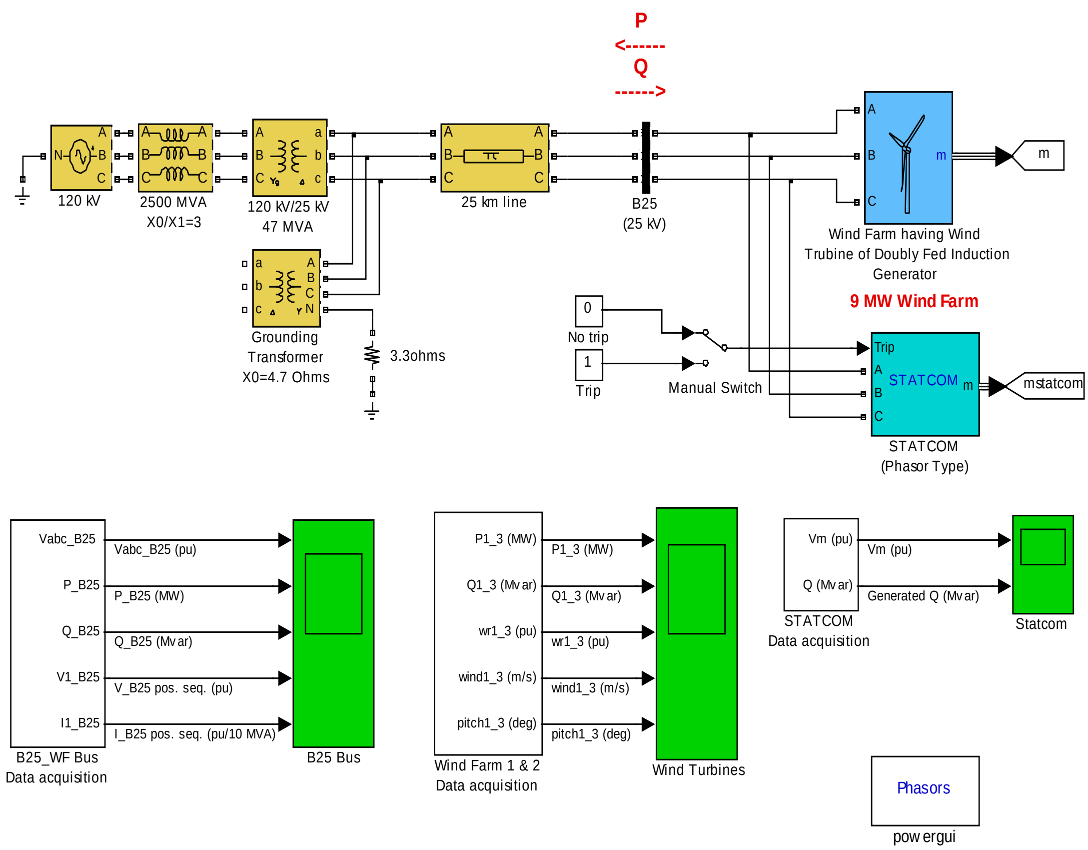

Figure 6. Simulated Model of DFIG Wind Turbine with STATCOM

In the simulated model, a wind farm is considered of six 1.5MW wind turbines which are connected to a 25kV distribution system exports power to a 120kV grid through a 25km 25kV feeder. The 9MW wind farm is comprised of three 1.5MW wind-turbines. In the simulated model, the wind turbines use squirrel-cage induction generators (IG). The stator winding is connected directly to the 60Hz grid and the rotor is driven by a variable-pitch wind turbine. The pitch angle is controlled in order to limit the generator output power at its nominal value for winds exceeding the nominal speed (9m/s). For electricity generation, the speed of IGs is maintained slightly above the synchronous speed. Speed varies approximately between 1pu (per unit) at no load to 1.005pu at full load. Each wind turbine has a protection system which monitors voltage, current and machine speed.The reactive power absorbed by the IGs is partly compensated by capacitor banks connected at low voltage bus. The capacitor bank is of 400 kvar for each pair of 1.5MW turbines. In order to maintain the 25kV bus voltage close to 1pu, the rest reactive power is provided by a 3 Mvar STATCOM with a 3% droop setting. The mechanical power of the wind turbine is a function of turbine speed ranging from 4m/s to 10m/s. The nominal wind speed yielding the nominal mechanical power of 1pu (3MW) is 9m/s. The wind turbine and the STATCOM model are phasor models that allow transient stability analysis with simulation time duration of 20s. The wind speed of three wind turbines is varied from the wind farm block. The simulated model is shown in Figure 6.

4.1. Simulation Results and Impacts of STATCOM

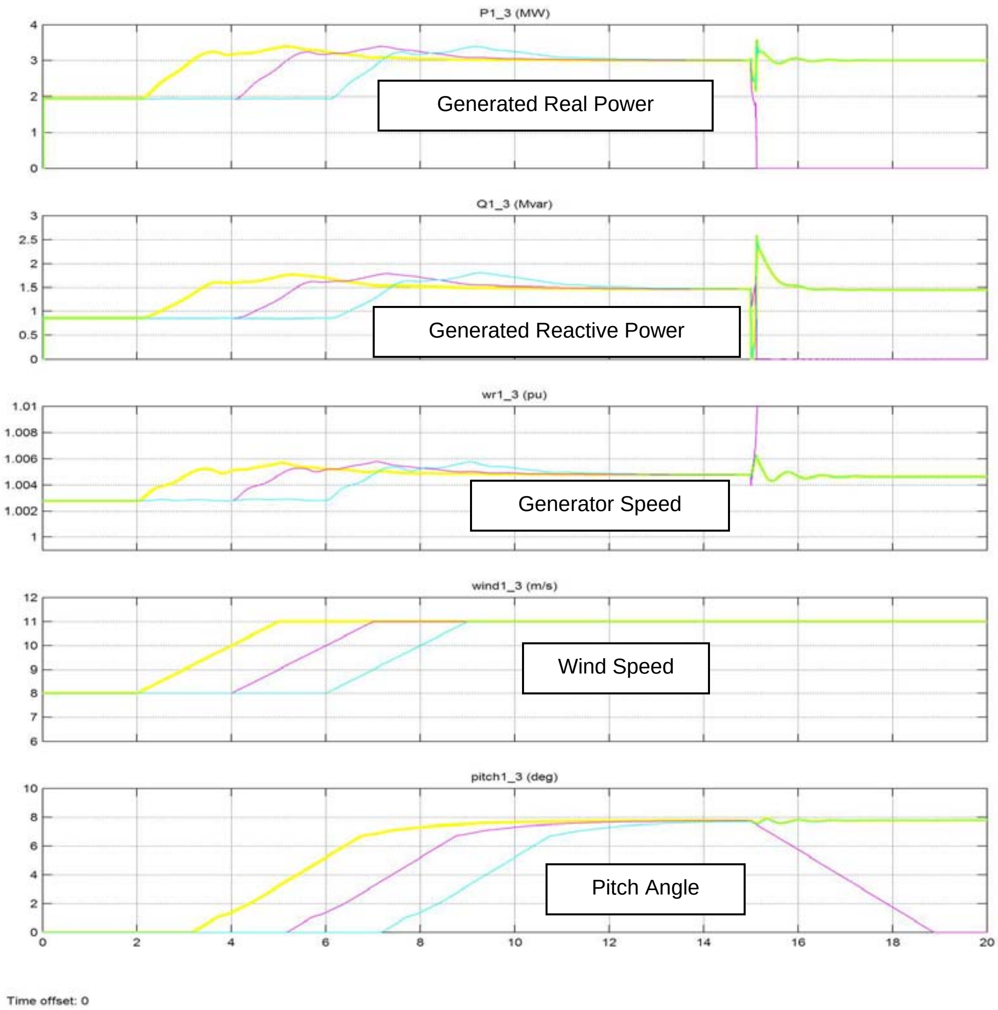

Figure 7. Improvement of Power of the Electric Network with STATCOM

Time

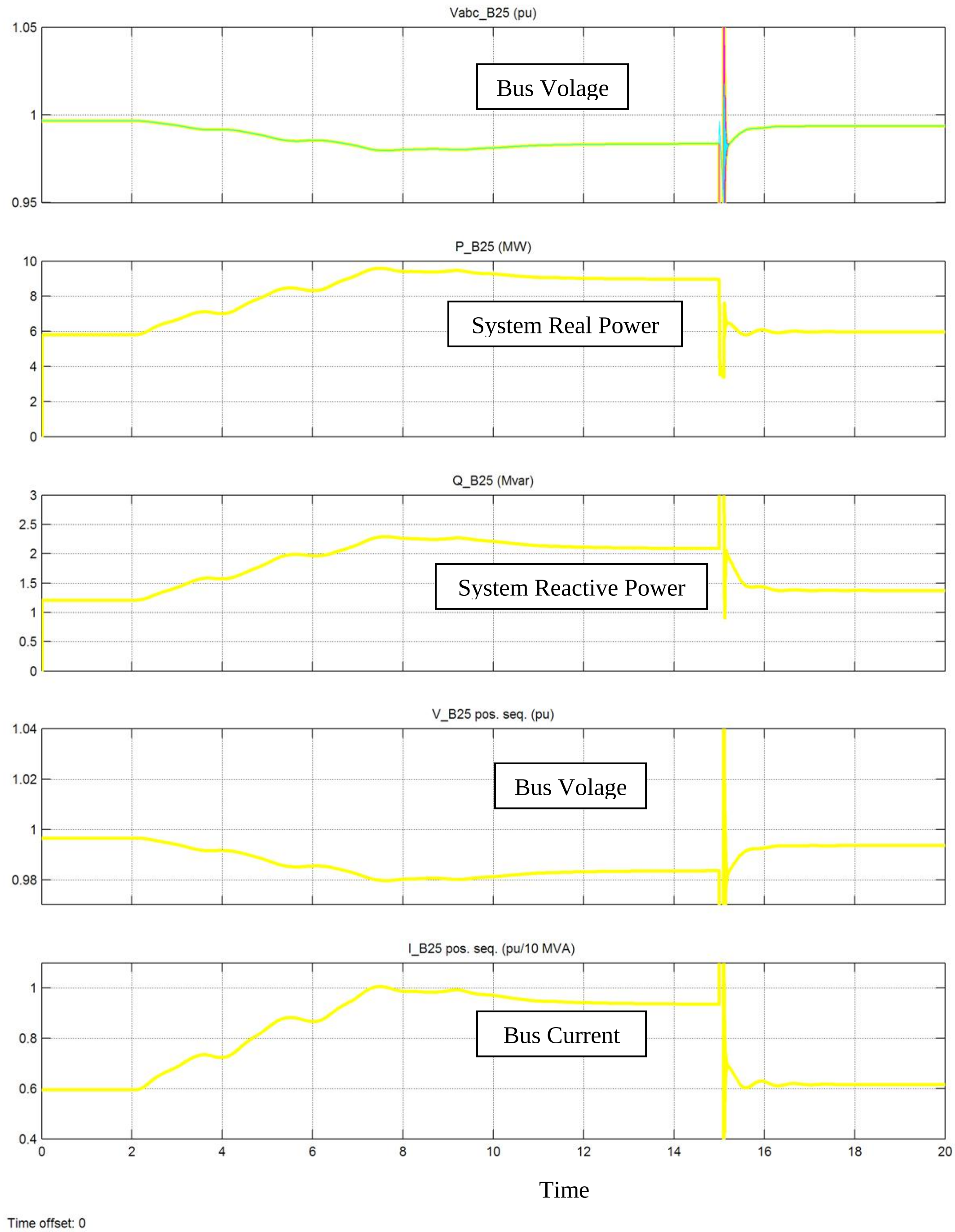

Figure 8. Drop in System Voltage after Removal of STATCOM from the Network

The Figure 7 shows the simulated waveforms of the generated active power, reactive power, generator speed, wind speed and pitch angle of each wind turbine with respect to change in wind speed. The generated electricity from wind turbine greatly depends on the wind speed which can be identified from the waveforms of Figure 7. For each pair of turbine, the generated active power starts increasing smoothly and reaches to its rated value of 3MW in approximately 8s. The turbine speed increases from 1.0028pu to 1.0047pu within that time. Initially, the pitch angle of the turbine blades is zero degree. When the output power exceeds

3MW, the pitch angle is increased from 0deg to 8deg in order to bring output power back to its nominal value. It is to be mentioned that the absorbed reactive power increases as the generated active power increases. At nominal power, each pair of wind turbine absorbs 1.47Mvar. For a wind speed of 11m/s, the total exported power measured at the bus B25 is 9MW and the STATCOM maintains voltage at 0.984pu by generating 1.62MVar. The effect of using STATCOM in the system can be observed by disconnecting the STATCOM block and immediately the bus B25 voltage drops to 0.91pu and therefore low voltage initiates an overload of the IG of wind turbine 1. The Figure 8 shows the waveforms of voltage, real power, reactive power and current of bus B25 when STATCOM is disconnected from the system. The bus voltage starts to drop while the current increases and the real power and lagging reactive power also increase. The wind turbine 1 is tripped at t=13.43s due to overcurrent protection. When the STATCOM block is connected to the system again then the bus B25 voltage increases to 1pu and system stability is maintained by providing reactive power of 1.65MVar.

4. Conclusion

The system stability is the main concern of the modern electrical power system network where electricity generation comes from both conventional and renewable sources. The STATCOM provides better voltage regulation than the conventional static var compnesator in case of system imbalance. From the simulated model it is observed that the STATCOM stabilizes the system voltage near to the rated value (1pu) when generated electricity from wind turbine is feeded into the system. Moreover the STATCOM responds to system imbalance within short time and stabilizes the system voltage to rated value. Therefore it can be a better option for the reactive power compensation than the conventional static var compensator.

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